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Eyesweet and colour science in cosmetics

The 1968 Medal Lecture by BRIAN H. CRAWFORD, D.Sc., Imperial College of Science and Technology, Department of Physics, London, S.W.7, delivered before the Society of Cosmetic Chemists of Great Britain, on 22nd March 1968, with David E. Butterfield, President of the Society, in the Chair.

THE CHAIRMAN: It is a great pleasure to welcome so many of you to the Society's 4th Medal Lecture. In previous years lecturers have included experts in various disciplines relating to the cosmetic industry. Tonight is no exception and we are privileged to have with us Dr. B. H. Crawford, who is an authority on vision and colour. He has devoted practically a lifetime to research in these fields and his work has rightly gained him an international reputation. Perhaps most significantly for us it has had far reaching practical effects in various fields of vision and colour lighting.

Dr. Crawford was in charge of the Colorimetry and Applied Photometry Section of the National Physical Laboratory until 1966, when he retired to take up a more academic life in the Applied Optics Section at Imperial College. He was chairman of the Colour Group of the Institute of Physics, and has been a member of international committees.

Synopsis—A brief outline is given of the four factors which make up colour perception: character of light source, character of object viewed, structure and function of the eye and final seat of perception in the brain. Consideration is then given to the measurement of colour in terms of the trichromacy of vision, both by direct colorimetry and by spectral analysis followed by calculation. The uses and limitations of colour atlases are described, together with an estimate of the number of tints or shades which are significantly different from the point of view of the cosmetic chemist: it is of the order of 100,000. Colour rendering, or the effect of the light source on colour appearance, is given special attention since it can be very deceptive for the fluorescent lamp which is now in such wide use; this is especially true with metameric colours, the nature of which is explained. Finally, certain phenomena are described which are, in a sense, colour illusions: the size of a colour stimulus and its pattern relation to other coloured stimuli can alter its appearance to an extent which is sometimes striking, indeed, almost unbelievable. Such extreme cases are rare, but more subtle effects are common, though often unnoticed except by the artist, who perceives what he sees, not what he thinks he ought to see.

INTRODUCTION

The cosmetic chemist provides the material basis for a branch of the art of make-believe: to what extent can our knowledge of colour perception and its mechanism help him in his task? At first sight it would seem that colour science can contribute almost nothing. The argument would be that cosmetic colours are dictated by fashion, that fashion is the imitation of the few by the many, and that these few are original spirits who may do anything; they are unpredictable, so where can science come in, since science is a body of knowledge gained in the past? The fashion innovator is only a human being, however, and so it is not impossible that his, or her, behaviour could be psychologically predictable if we knew enough psychology. In particular, he has colour perception within a well-defined range: even his world of make-believe has to be seen according to certain rules and regulations, and thus it may be profitable for the cosmetic chemist to have some knowledge of the range and mechanism of colour perception and of the techniques which have been developed for the measurement of colour.

In the first place, what is colour? Every normal person, neglecting the ten per cent or so who have defective colour vision, has a keen sense of colour: everything around him appears to be "coloured". It is vitally important, however, to make an analysis of the factors which go to make up this "colour". It results from the interaction of four factors—the light without which we can see nothing, the surface or bulk properties of the objects we look at, the eyes with which we look at them, and the brain which is the final seat of perception. Colour does not reside in any one of these factors by itself.

Light

The light from the sun, our most universal illuminant, or from a tungsten filament lamp, our commonest artificial illuminant, can be analysed into what appear on first consideration to be different colours, spread out in what is called a spectrum. The only physical attributes which can be attached to the various locations in the spectrum, however, are wavelengths (or frequencies) which in themselves are not in any sense descriptions of colours. Neither is colour an attribute of the white screen on which the spectrum is formed: the screen merely re-directs the radiation into the eye of the observer.

The eye

Is "colour" then in the eye? An eye, when no longer wanted by its natural owner, can be excised and taken to pieces. It is found to be very

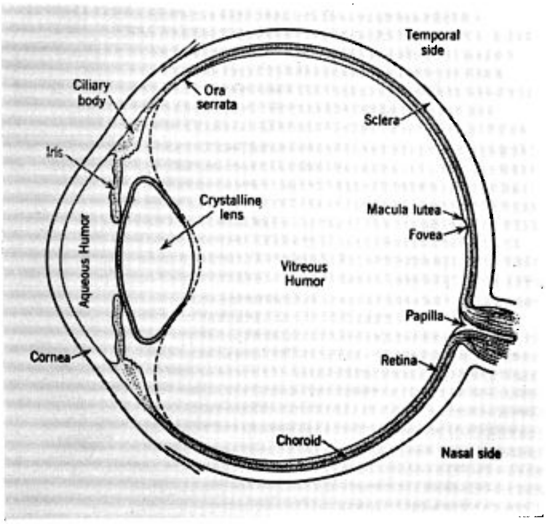

Figure 1 Section of human eye.

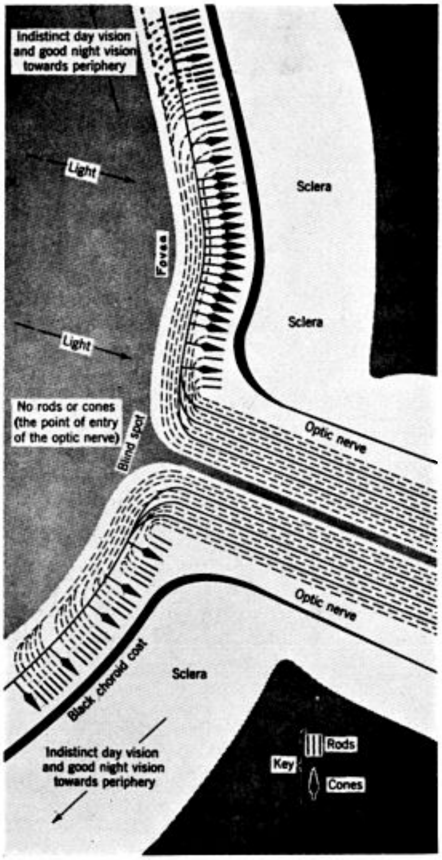

Figure 2 Section of the back of the human eye.

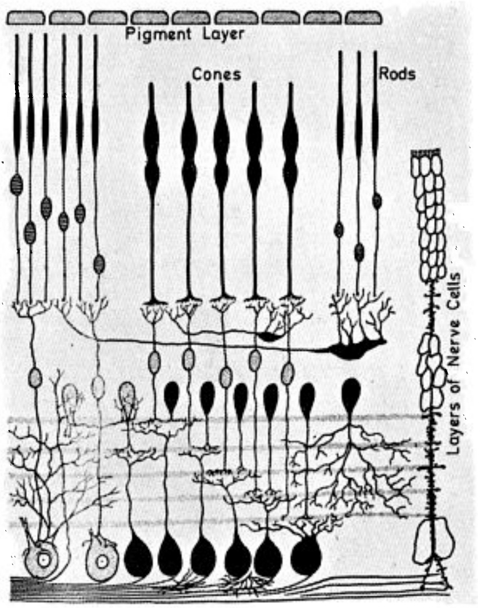

Figure 3 Section of retina showing some of the immense complication of receptors (cones and rods) and nerve connections. The cones are at present presumed to be of at least three kinds in order to implement the trichromacy of colour vision.

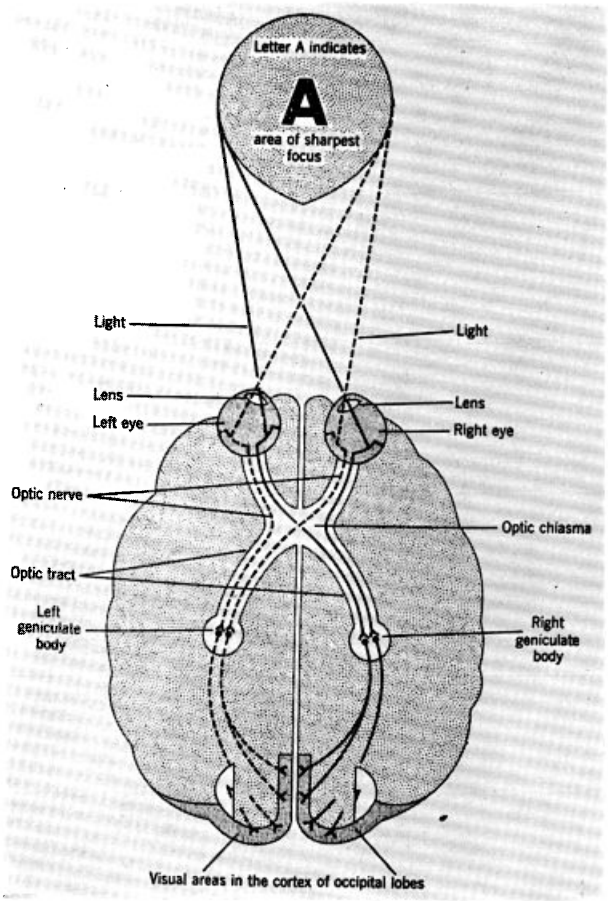

Figure 4 The general scheme of connections between external field of view (top of diagram), the eyes and the brain.

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much like a little camera, with a lens in front and a screen at the back on which the lens can form an image (*Fig. 1*). The screen is immensely complicated and has not yet yielded up all the secrets of its structure and function, but we know enough to realise that it is a fine mosaic of light-sensitive elements, minute photocells, each of which is eventually connected to the brain by a complex system of nerve fibres (*Figs. 2–4*): light of different wavelengths may be supposed to affect these photocells to different extents, so that they can send impulses to the brain which depend upon the wavelength and upon the particular photocell stimulated. There is still nothing in this which could be called "colour", only an absorption of radiation and an initiation of a nerve impulse, purely physical and electrical processes. The nerve impulses travel along the optic nerve to more and more distant stations in the brain and there, for the present, all definite knowledge has its boundary. We can only say that somewhere in the brain there occurs what we call perception of colour, perhaps in minute particular localities, perhaps in ill-defined patches, perhaps all over the brain as in the holographic concept recently put forward by Longuet-Higgins (1).

To the tidy-minded scientist this is a distressingly vague ending, but fortunately the various factors which precede it are amenable to quite precise description and measurement, and to this extent the "perception of colour" is well understood.

COLOUR VISION

We have seen how light can be analysed into its component wavelengths which finally excite different colour perceptions in the brain. When the original mixed light falls upon a surface it is in part reflected back, the rest being lost by absorption within the surface. A white surface is one which reflects equally and almost completely all wavelengths of light; a grey surface reflects equally but only partially; a coloured surface reflects both partially and unequally. The appearance of colour results from the loss of parts of the original white light: what is not lost is reflected back (*Fig. 5*), and can be seen by the eye. This selection of spectral intensity is the only function performed by a surface, or by a transparent substance such as stained glass, in the production of colour. Nevertheless, the property of "colour" is commonly ascribed to surfaces, pigments, glasses, liquids, etc., as if it belonged solely to them. In fact, the most intricate and mysterious part of the process of seeing colour comes only when light has travelled from source to surface and from surface to eye.

As soon as the light has been absorbed, wholly or partially, by the receptors of the retina, its role is finished. It is transformed into nervous impulses which travel to the brain. In some way these impulses must carry the information, previously carried by the light, coded in such manner that the colour information in the light is perceived by the brain. There is little doubt that the primary coding at the level of photoelectric transformation in the receptors is followed by many re-codings, cross-codings and group-codings. The surprising thing is that, through the intricate maze of our higher nervous system, perception finally occurs in such perfection, crystal-clear and, usually, unambiguous.

The disentangling of the various stages of nervous transmission and coding is one of the great preoccupations of the sensory research worker at the present time, but the nature of the primary, receptor coding has been well established for many years. It is described as the trichromatic theory of vision, first proposed by Young (2, 3), who was unconciously following up an idea proposed by Wünsch (4); it was forgotten for many years, then later revived by Helmholtz (5) and given an experimental basis by Maxwell (6).

The experimental fact which provides the basis for this theory is that the colour of any light stimulus, whether coming to the eye direct from a source, or after reflection at a surface, can be matched in appearance by a mixture, in appropriate proportions, of not more than three chosen stimuli, i.e. the three chosen stimuli are all shown upon the same area of a screen and can then be adjusted to match in appearance any other light stimulus. This principle is illustrated by *Fig. 6.* It must be admitted that this statement is an over-simplification, but the only extension we need consider is that one or other of the three chosen stimuli, called the primary stimuli, must sometimes be imagined as having a negative value. This is, of course, physically impossible: what happens in practice is that certain stimuli must have one of the primaries mixed with them in order to match the mixture of the other two. It is rather like an algebraic equation in which

$$\text{Test}+\text{Primary A}=\text{Primary B}+\text{Primary C}$$

This is physically possible, but on paper can be algebraically transformed to

$$\text{Test}=\text{Primary B}+\text{Primary C}-\text{Primary A}$$

which is physically impossible but preserves the basic concept of the trichromatic theory. These primaries, A, B, and C, are physical stimuli, but they can be transformed algebraically into three *fundamental sensations* (7)

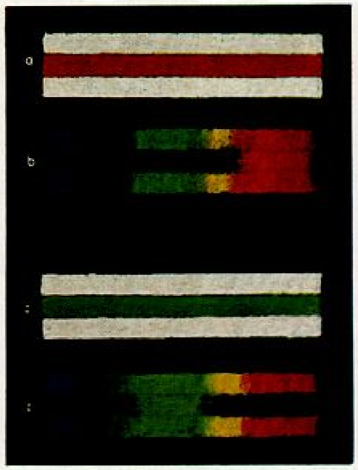


Figure 5 Action of pigments in modifying light.
a, strip of white paper with band of orange-red pigment down the centre;
b, the same illuminated by the spectrum of white light;
c, *d*, the same demonstration for a band of green pigment.
The pigment reflects light of its own "colour"; in other parts of the spectrum it absorbs the light and appears grey or black.

Figure 6 Additive colour mixture. Red, green and blue light when shone upon a screen blend to give the appearance of white (centre of diagram). When only two lights blend they give the appearances of yellow (red + green), blue-green (green + blue), or purple (blue plus red).

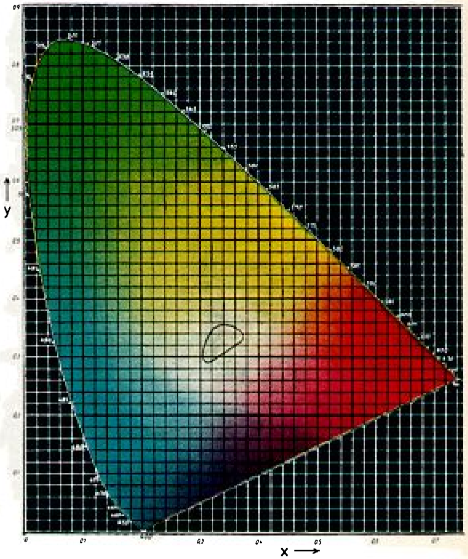


Figure 9 The CIE chromaticity chart on which all chromaticities of colours can be plotted and so displayed as on a map.

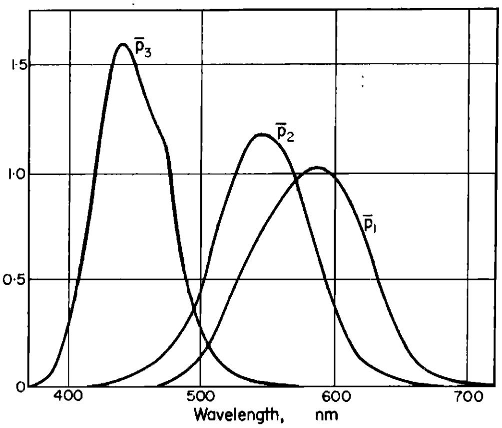


Figure 7 The response functions of the three colour receptors of the normal retina: the spectral sensitivities are deducted from measurements of colour mixture.

which would always be *positive quantities* when added to match a given test stimulus. These fundamental sensations can correspond to real physiological mechanisms, although not to real physical stimuli. It is supposed, therefore, that the retina contains three kinds of receptors, all with some sensitivity in all parts of the spectrum, but with maxima of sensitivity in the blue, green and red regions. There is still discussion as to the actual form of the three fundamental sensation curves; an example is given in *Fig. 7* which has a reasonable theoretical foundation.

Some ninety per cent of most populations have closely similar receptor systems and are said to be "normal" (in respect of their colour vision). It is presumed that they all have rather similar perception of the outside world: there is no genius in colour perception. The remaining ten per cent or so deviate from the normals, often quite startlingly, which may be explained by deficiency, modification, or complete absence of one or more of the three normal colour receptors. No one has yet suggested that any form of colour vision should be explained by the presence of *more* than three receptor types in one retina.

COLOUR SPECIFICATION

The result of this hypothesis, which has been amply confirmed for practical purposes, is that colour can be quantitatively specified. It can be calculated from the spectral energy distribution of the source of light, the spectral reflection properties of the object observed, and the spectral sensitivities of the three visual colour receptors (the so-called colour matching functions). Colour can also be measured by various pieces of apparatus, types of colorimeter, which abbreviate the calculation method. It must be admitted that there is not yet complete certainty as to the true values of the response functions of the receptor mechanisms, but they can be conventionally evaluated in terms of standard conditions of observation as colour matching functions, which give all that is necessary for the specification of colour in terms of chromaticity and luminance for the normal or "standard" observer. The system set up by the Commission Internationale de l'Éclairage has many convenient features and is almost universally used: *Fig. 8* shows the colour matching functions of the system, *Fig. 9* the chromaticity diagram in which the calculated or measured values are usually exhibited.

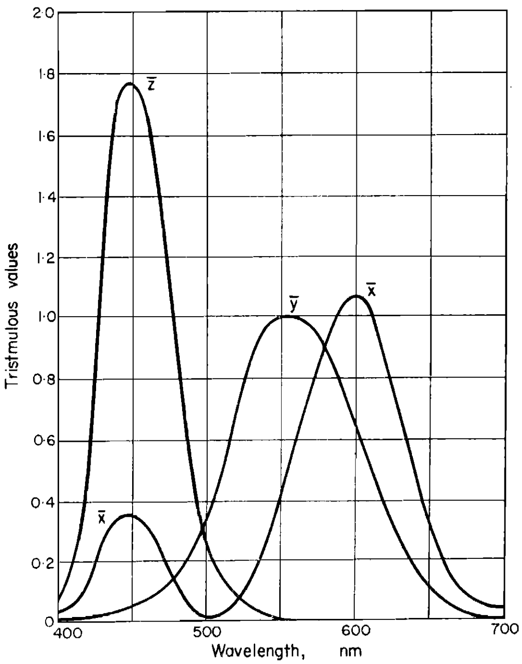


Figure 8 The CIE colour matching functions: these are analogues to the response functions, but adapted to the purposes of chromaticity measurement.

The first deduction from this specification of colour is the nature and finite extent of "colour space": no colours can be more saturated than the spectral colours and the "purple boundary" which joins the red and violet ends of the spectrum locus on the chromaticity diagram. Among surface colours none can be lighter than the perfect white diffuser, which reflects all that falls upon it, or darker than the perfect black, which reflects nothing. A little thought shows that within this colour space there can only be a finite number of colours which the eye can distinguish. This follows because there is a limit to the smallness of colour difference which the eye can detect, often called the threshold or limen of perception. Thus colour space can be thought of as occupied by a number of cells, like those of a honeycomb but extending in all directions, each cell having a diameter equal to the threshold of colour difference perception. One has only to divide the volume of colour space by the volume of a cell to obtain the total number of distinguishable colours. In practice this is not so simple as it sounds, since the size of cell is not constant and no linear distortion of colour space will make it so. Experimental determinations of cell size are also far from complete, but a fairly reliable estimate was made by Nickerson and Newhall (8). The figure was 7½ million colours, just distinguishable by highly skilled observers under the best possible conditions. This number is to be divided by four to give the number of easily distinguishable colours, then by eight to give the number in the pigment range, then by two to give the probable number of colours which are of cosmetic interest (although it is becoming increasingly doubtful whether there is such a thing as a colour which is not of cosmetic interest). The result is of the order of 100,000. Even this reduced number is very large and it may be that cosmetically different colours are more widely spaced than has been assumed above.

It is clear, even so, that the cosmetic chemist is concerned in the production and control of a rather large number of colours and the question arises whether the techniques of colour measurement could be of any assistance. The best photoelectric colorimeters can distinguish colour differences which are imperceptible to the eye, but their absolute accuracy is poor: they excel at measuring differences, so that the method of application to colour control would be the measurement of differences between test samples and an appropriate permanent standard, such as a glazed ceramic tile, selected from a limited number which cover the field of interest. These standards would be calibrated once for all by careful spectrophotometry, followed by calculation of chromaticity.

These methods of exact colour measurement are not only appropriate to quality control during manufacture; they also form the basis of colour formulation for the production of new colours, i.e. the empirical relation between a chromaticity desired for fashion reasons and composition in terms of pigment mixtures. Quality control during manufacture may be very simple in the case of coloured cosmetic products, but it is worth remembering that quality control by chart methods is only possible when the product can be measured, in this case in terms of chromaticity: the more sensitive the measurement of chromaticity, the earlier the detection of deviation in quality of product.

COLOUR ATLASES

It is also desirable to mention the nature, possibilities and limitations of colour atlases. A complete colour atlas contains samples of surface colours which cover the whole possible range, and are displayed in some sort of logical manner for ease of reference. In a good colour atlas, the spacing of the colours follows a uniform, reproducible perceptive scheme. With sufficient patience, a logical array of colours can be set up: the *Munsell* atlas is one of the best, and best known. The colours are so spaced that each is at a perceptually equal distance from each of its neighbours. Unfortunately, no atlas can be used for accurate measurement by comparison of an unknown coloured surface with the "chips" of the atlas: adequate reproducibility and permanence are not attainable except by doing so many and such frequent measurements that the atlas loses its point. One might as well do the measurements without the atlas.

All the same, atlases have their uses, especially when the colours are arranged at equal sensory intervals, as in the *Munsell* atlas. In so far as design of cosmetic colour schemes is possible, the arrays of equally spaced colours of an atlas provide ideal material for the purpose. The aesthetic and psychological factors of colour harmony, colour contrast, colour rhythm, etc., may be explored with facility, using the atlas chips on various backgrounds, which may be larger specimens of the atlas colours. The details of such aesthetic and psychological factors are outside the scope of this lecture and are, indeed, extremely difficult to investigate: a great deal of work has been rendered futile through ignorance of the known facts of colour perception. It behoves any would-be investigator to make himself thoroughly familiar with these facts before embarking on his aesthetic or psychological journey.

ILLUMINATION AND COLOUR

So long as an illuminant looks more or less white it is easy to assume that it has no particular importance in the perception of the colours of

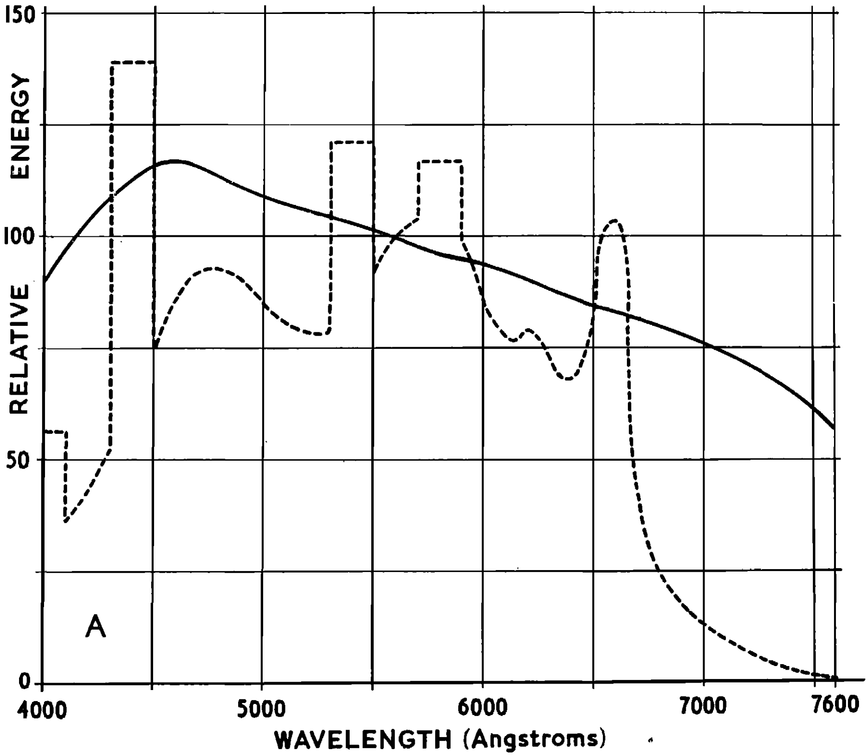


Figure 10 Spectral energy distributions of daylight and a fluorescent lamp designed to imitate it. The sharp peaks due to the mercury lines and the strong deficiency in the deeper red should be noted.

objects seen by it. The advent of the fluorescent lamp was the great single factor which disturbed this complacent attitude. Previously, the only commonly noticed effect was the difficulty of matching the darker blue or purple materials in artificial light: it became second nature to go to the nearest door or window where there was some real daylight. The advantage was partly the greater intensity, partly the greater proportion of blue in daylight by comparison with the tungsten filament lamp which used to be almost the only artificial source of light.

The fluorescent lamp provides a much greater amount of light for a given electric input, so that it is easy to rival daylight levels of illumination, but unfortunately the spectral energy distribution is peculiar, as may be seen from *Fig. 10* in which daylight is compared with the light from a fluorescent lamp. The colour of the fluorescent light itself, seen when it illuminates a white surface, may be very satisfactorily white, but the presence of the mercury line radiation and the low efficiency of the red-producing phosphors inevitably spoil to some extent, even seriously, the imitation of daylight. This is apparent as soon as coloured objects are looked at, not only whites and greys; under the highly efficient "daylight" fluorescent lamps, which look white but have a serious deficiency in the red part of the spectrum, tea and coffee look yellowish and unpleasant, red carpets look brown, butter acquires an unnatural jaundiced appearance, complexions look dirty, etc. These phenomena are grouped under the term "colour rendering of light sources". To a certain degree, one can be trained or brain-washed to disregard abnormalities in colour rendering, but not entirely. No one with normal colour vision would ever accept mercury or sodium street lamps as giving satisfactory colour rendering. On the other hand, many of the better fluorescent lamps are acceptable, at least for many purposes, as imitations of daylight, or just as pleasant sources of light. There is obviously, somewhere, a kind of threshold of acceptability, an engineering tolerance within which the spectral composition of light sources must lie in order to render colours satisfactorily. At first sight it might seem that the determination of a threshold of acceptability is insuperably complex, involving as it does variations in spectral composition all through the spectrum, each part of the spectrum contributing its quota to the general appearance of all colours in a realistic situation. No doubt this apparent complexity inhibited experiment for many years, so that the only methods of controlling colour rendering were common sense, guesswork and the misguided application of existing data from other fields of colour vision. In fact, the problem is not so recalcitrant as it seemed. For example, a series of carefully designed psycho-physical experiments carried out under my direction at the National Physical Laboratory showed that a comparatively simple system of colour rendering assessment could be used with great practical success.

The first step in the colour rendering assessment of a source of light is to have an analysis of its spectral quality. The question is, how detailed need the analysis be? As a basis for colorimetric calculations, an analysis of 40, or 80, or even 400 bits of information is used, each "bit" being a relative energy measurement in a spectral band. Since the calculation ends up with only three bits of information, viz. the two chromaticity co-ordinates and the luminance factor, it would seem that a lot of information has been thrown away. It is interesting to follow up this analysis of visual perceptions into bits of information. One bit can be regarded as the total intensity of the source, a measurement including the whole spectrum. Two bits can give the equivalent colour temperature of the source by comparing the intensities in the two halves of the spectrum. Three bits give the colour, either of a source or of an object illuminated by it. One-bit information is provided by a photometer, two-bit information by a colour temperature meter, three-bit information by a colorimeter. Six bits of information were found sufficient for adequate assessment of colour rendering in all practical cases so far treated: the six bits are the relative luminosities in six spectral bands which together cover the whole visible spectrum. The use of more than six (or possibly seven) bits would be impossible experimentally since, on the average, an observer does not notice anything wrong with colour rendering until about half of any one of these six spectral bands is missing.

COLOUR RENDERING ASSESSMENT

Experiments on the trichromacy of colour vision stretch back in time over more than 100 years, those on colour rendering over a mere 10 or 15, so it may be useful to give a very brief general outline of the latter, based on the NPL work which may be taken as representative.

Light from a source accurately equivalent to daylight was dispersed into a spectrum and then recombined. The apparatus was essentially a very large double monochromator so designed that the *whole* of the central spectrum was recombined without loss. At the location of the central spectrum, screens could be inserted so as to produce any desired modification, sudden or progressive, in the composition of the finally emergent light. If the latter was used to illuminate a picture, an object such as tea, coffee, butter, meat, etc., or a face, the colour rendering could then be judged while changes were made in the composition of the illuminant. By signalling the first onset of perceptible change, the observer made a determination of threshold, or tolerance, in colour rendering. There are, of course, many more experimental details and conditions involved, which can be studied in the original communications (9), but the final results which emerged were unexpectedly simple.

Colour rendering is always assessed by conscious or subconscious comparison with something, there is no absolute measure of it. The most logical standard with which to compare is a phase of daylight, since daylight is the natural and most common illuminant, and it is in relation to daylight that our colour perception system has evolved. It is further proposed that the colour rendering properties of a source should normally be assessed in relation to a phase of daylight of the same equivalent (correlated)

Table I

Spectral band limits (nm) and number	Band luminance		Ratio of luminances (test/ reference)	Deviations from unity		Excesses outside tolerances	
	test source	reference source		single bands;	double bands (per cent)		
400-455 (I)	0.431	0.382	1.13	+13		3	
			(1.06)		+ 6		1
455-510 (II)	7.37	7.51	0.98	— 2		0	
			(0.89)		—11		6
510-540 (III)	15.0	19.1	0.79	—21		11	
			(0.94)		— 6		1
540-590 (IV)	48.8	44.8	1.09	+ 9		0	
			(1.04)		+ 4		0
590-620 (V)	18.0	18.3	0.98	— 2		0	
			(1.01)		+ 1		0
620-760 (VI)	10.3	9.93	1.04	+ 4		0	
						Total excesses = 22	
400-455	0.584	0.439	1.33	+33		23	
			(1.03)		+ 3		0
455-510	5.92	8.07	0.73	—27		17	
			(0.68)		—32		27
510-540	12.5	19.8	0.63	—37		27	
			(0.93)		— 7		2
540-590	55.0	44.7	1.23	+23		13	
			(1.18)		+18		13
590-620	19.8	17.6	1.13	+13		3	
			(0.90)		—10		5
620-760	6.21	9.35	0.66	—34		24	
						Total excesses = 154	

colour temperature. The next step is to compare the test source with the standard source for luminosity in six spectral bands. The latter have been chosen experimentally to have as nearly as possible equal colour rendering weight, i.e. the loss of the same fraction of any one band will be equally noticeable. Experiment showed that, on the average, the loss of 40% of any one band was just noticeable. The adoption of 40% as the production tolerance would be wrong, however, as it would only satisfy half the population: it is necessary to adopt a more stringent tolerance so that a large proportion of the population will be satisfied. A tolerance of 10% is suggested, which satisfies 95% of the population. Should a pair of adjacent bands deviate in the same sense from the standard, this tolerance drops to 5%. *Table I* and *Fig. 11* show an example of how this colour rendering assessment works in practice. The final result may be boiled down to a single figure or class of general colour rendering excellence, or it may be

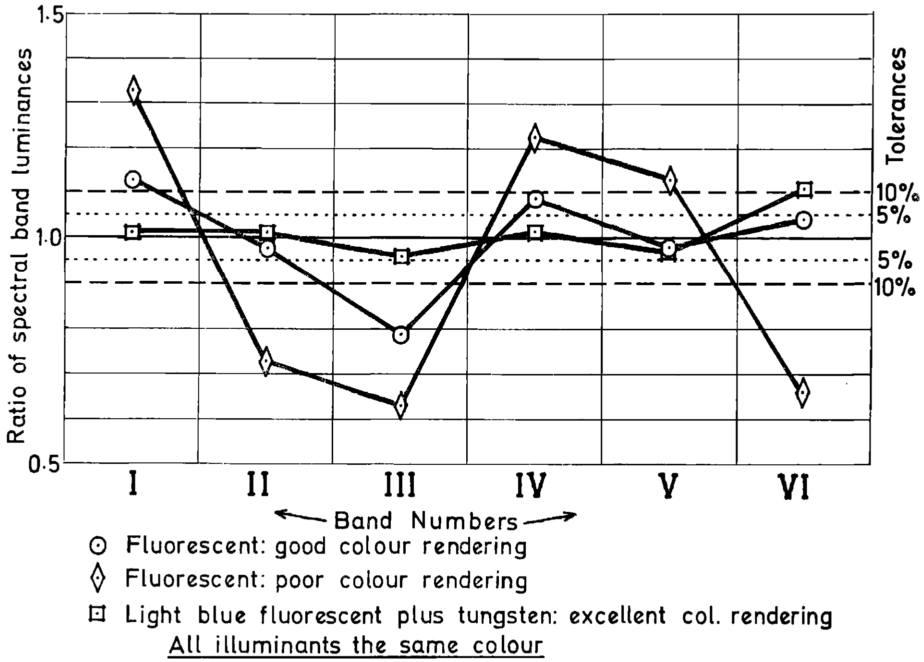


Figure 11 Graphical portrayal of colour rendering assessments.

left in its more detailed form, in which case the diagrammatic presentation gives a quick appreciation of the performance of the illuminant under test. In judging from the graphical assessment it must be remembered that two wrongs do not make a right: too little in one band is never compensated by too much in another. Indeed, the whole meaning of the colour rendering bands is that they are of such widths that within them the eye is almost unaware of differences in the distribution of radiation, but between them, very much aware.

Colour rendering is important in relation to the general appearance of people, clothes, scenes, pictures, interiors, a.s.o., but it is has special significance when pairs of coloured surfaces in a scheme are metameric. Metameric surfaces are those which look the same under some given illuminant, but, in fact, have different spectral reflectance curves: in consequence, under any other illuminant, they will look more or less different from each other. Manufacturers avoid metamerism like the plague, if they can, but complete avoidance is impossible when different materials have to be

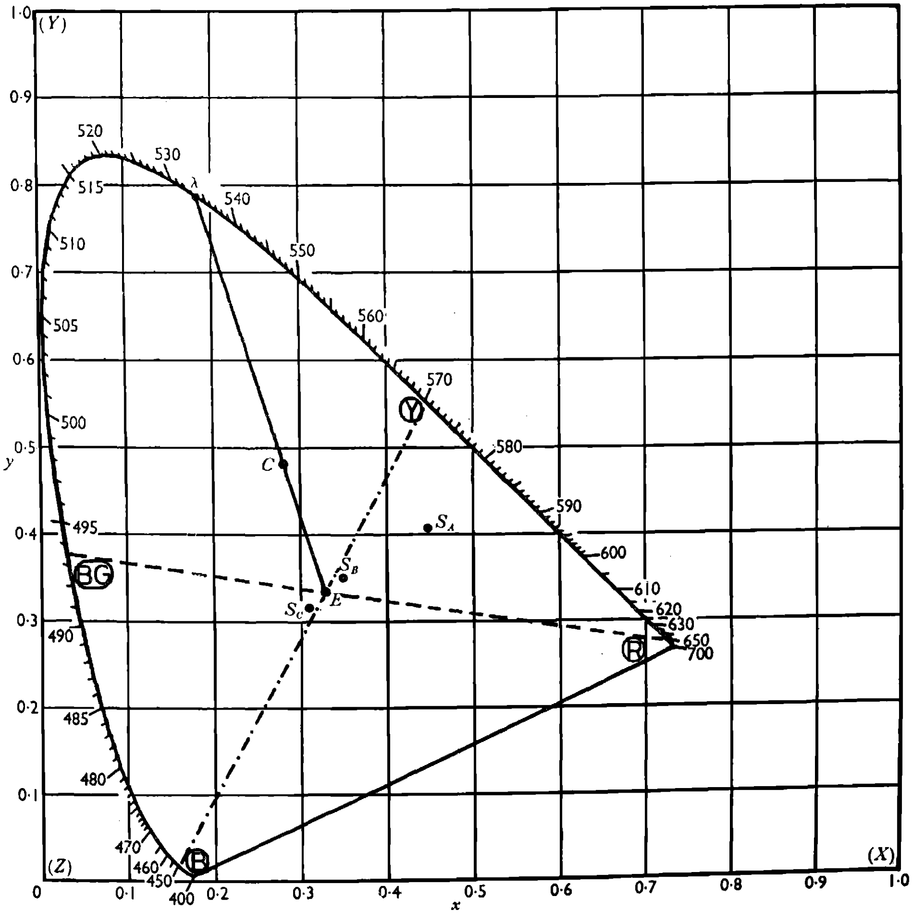


Figure 12 Graphical method for choosing complementary pairs of colours with the help of the CIE chromaticity chart. The broken lines through the white point join the pairs of colours.

matched in colour; dyes "take" differently, pigments differ from dyes, etc.

The mechanism of these metameric changes in colour may be understood from a simplified example. Pairs of complementary colours, when mixed in correct proportion, give the appearance of white or grey. *Fig. 12* shows how pairs of complementary colours may be chosen from the chromaticity chart. *Fig. 13* shows a rather extreme example of a metameric pair of greys made up in this way, a red-plus-blue-green mixture and a blue-plus-yellow mixture. It would be possible to produce these two varieties of grey by intermingled pigment spots, interwoven threads or other means.

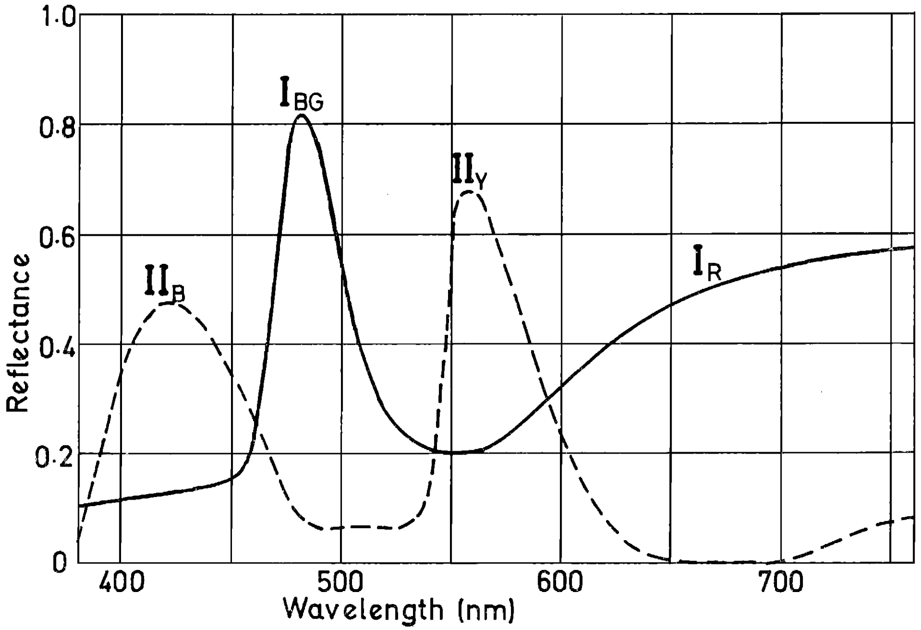


Figure 13 The spectral reflectance curves of a pair of metameric greys, I(BG)-I(R) and II(B)-II(Y).

The effective spectral reflectances would be approximately as in *Fig. 13,* the relative intensities of the various reflection peaks being adjusted to suit, say, standard mean daylight. If now the red part of daylight were greatly reduced, it is fairly obvious that colour A would be vastly altered, to a blue-green, while colour B would hardly be affected.

There is an infinite number of variations in the composition of metameric sets of colours and in the degree of metamerism. Many of these are only theoretically possible, but there remain many practical occurrences of metamerism which are sufficiently strong to spoil colour schemes under changing quality of illumination. Avoidance is the easiest remedy, but if colours of very different materials must be incorporated in the one scheme there is still hope of success with the help of careful spectrophotometry to aid in selection of compatible dyes and pigments. One could also manage by trial and error without spectrophotometry, but it would be rather like the ocean navigators of the centuries before Captain Cook trying to find again an island in the Pacific Ocean: they never did, except by chance.

SUBJECTIVE COLOUR PHENOMENA

Having sketched some of those branches of colour science which might possibly be of use in cosmetics, it is only fair to balance the account by mentioning a few colour phenomena which, for the present, lie outside the realm of colour measurement. Some are subtle, some are startling, they nearly all occur when small patches of colour are viewed in close association with larger areas which contrast strongly in colour or luminance. One of the difficulties in the way of putting forward a universal theory of these effects is that some are apparently contradictory.

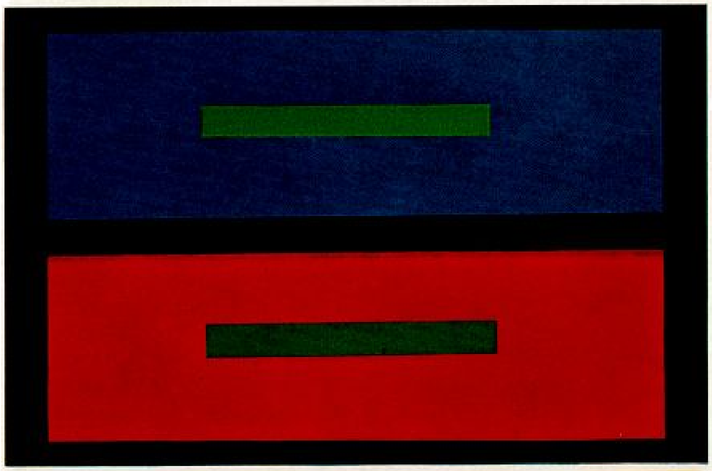
The first effect to be noted is the so-called "small-field tritanopia", or, in simpler terms, a relative insensitivity to blue in a small patch when directly fixated as compared with a much larger patch of the same physical quality ($\frac{1}{3}°$ *versus* 2° or over, subtended at the eye). This effect is not of great interest in patterns of surface colours.

Of much wider occurrence is the contrast effect in which the appearance of a small patch may be greatly modified by being in close association with a larger patch. For example, a small patch of grey will look lighter if surrounded by black, darker if surrounded by white. The same applies to small coloured patches, which show, in some cases, a slight change in hue as well. If the large surrounds are coloured, but there are no great differences in relative brightness, then modifications in colour of the small patches become noticeable (*Fig. 14*).

These effects may all be regarded as aspects of adaptation controlled by the large fields: the small patches have to fall into line with the larger. For instance, a middle grey is light compared with a black and will appear so when the eye's vision is dominated by black; on the other hand, if the domination is by white, the grey will appear dark. The colour effects from simple combinations of large and small fields may be explained along the same lines.

There is, however, a special group of effects in which narrow lines of one colour are closely spaced on a general field of another colour. Black lines darken the general background colour, white lines lighten it. Coloured lines drag the background colour towards their own colour. This phenomenon, known as the *von Bezold* effect (*Fig. 15*), is apparently in contradiction to the contrast effects. It is possible that it may be explained by scattering in the retina, in the eye media in front of the retina, or from part to part of the retina, whereas the contrast effects are more likely to be motivated at higher levels in the brain. The importance of the higher levels in the per-

Figure 14 The effect of colour contrast on colour appearance. The green areas are identical physically, but "repelled" by the colours of the surrounds.



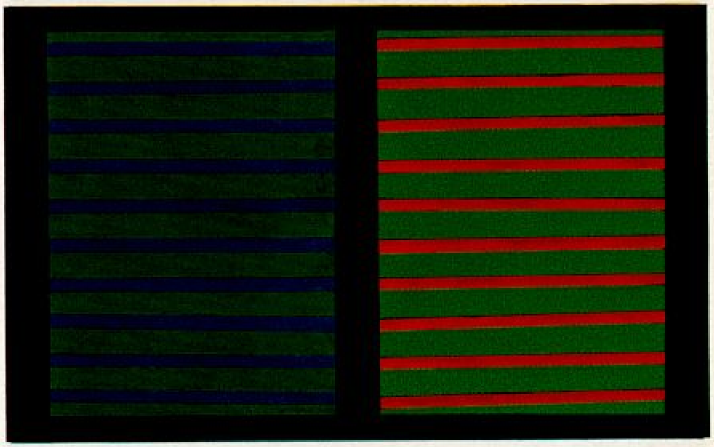


Figure 15 The von Bezold effect of thin lines of colour. The green areas are identical physically, but are "attracted" by the colours of the lines.

Dr. Crawford (left) being presented with the Society's Silver Medal by the President

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ceptive pathway is evident from the fact that some of the more subtle of the effects described are seen, or not seen, according to the mental attitude of the observer. If he thinks of the total colour effect in the spirit of the artist receptive to all outside impressions, he will see them; if he regards the colour array as a set of physical stimuli which he tries to analyse as objectively as possible, then the subtler effects will not be apparent to him. For progress to be made in the study and explanation of these effects, it is obvious that considerable care and cunning will be needed in devising suitably revealing experiments.

CONCLUSION

Coming finally to the title of this lecture, you will by now, I hope, have seen its meaning. Eyesweet describes what looks just right, the craftsman uses the term for the successful product of his craft, of his cunning of hand and eye which make a thing of beauty unpredictable by measurement. Science records what we know when we have measured the craftsman's work: it can tell the manufacturer how to make any given thing, but only eyesweet can tell him what to make.

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The Chairman then presented the lecturer with the Society's silver medal, amidst applause from the audience. This was followed by a vote of thanks proposed by the Vice-President of the Society, Mr. C. Pugh.